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Summary.—This report describes experiments on the effect of distributed suction on the stalling characteristics of a two-dimensional aerofoil, NACA 63A009.

The most economical extent of suction was from the leading edge for 2·75 per cent chord round the upper surface. At a Reynolds number of $1 \cdot 15 \times 10^6$, a suction-quantity coefficient C_Q of 0·0034 increased $C_{L\,\max}$ from about 0·86 to 1·50 by delaying the stall from 11-deg to 20-deg incidence.

Scale effect on the flow was investigated at 14-deg incidence. It was found that between Reynolds numbers of 6×10^5 and $3 \cdot 5 \times 10^6$ the suction-quantity coefficient needed to overcome the boundary-layer separation at the nose was approximately inversely proportional to the square root of the Reynolds number.

The aerofoil was also tested with a 20 per cent split flap at 60-deg deflection. The flap increased $C_{L\,\max}$ without suction from 0·86 to 1·74, but the further increment obtainable on applying suction was only 0·31. Suction thus only gave half the increase on the flapped aerofoil that it gave on the plain aerofoil.

The difficulty experienced in obtaining a high lift-coefficient was thought to be due to the small radius of the nose of the section. A modification was made by reducing the chord of the aerofoil 2 per cent and fairing the profile into a blunter nose of radius of curvature 0·010 chord instead of 0·0063 chord. The modified section (designated NPL 321) gave maximum lift coefficient only 0·1 greater than the corresponding ones for NACA 63A009 except when the flap was deflected with suction applied when the increase was 0·3, the $C_{L\,\max}$ then being 2·33.

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1. *Introduction.*—Preliminary wind-tunnel investigations into the effectiveness of distributed suction over the nose of a thin aerofoil in delaying the stall, and in increasing the maximum lift coefficient have been carried out in this country by Pankhurst, Raymer and Devereux[1] (1948) on HSA V (NPL 308) aerofoil and in America by Nuber and Needham[2] (1948) on NACA 64_1A212 aerofoil. The present experiments were undertaken to add to the available knowledge by testing another section. In particular, information was sought on scale effect on suction quantity, on the effect of distributed suction on a flapped aerofoil and on the influence of the shape of the nose of the section on the maximum lift coefficient obtainable with suction.

The HSA V section previously tested was 8·2 per cent thick and had been specially designed to have a very large leading-edge radius of curvature ($\varrho_L = 0 \cdot 03c$). Although a velocity peak was present at the nose at zero incidence, the adverse velocity gradients at high values of C_L were less severe than usual. However, the design calculations produced an aerofoil shape with

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surface curvatures greater a little way back than that at the leading edge, forming a pair of shoulders. These were believed to be the cause of the local separation which was observed at all incidences without suction and may have accounted for alternative régimes of flow that were discovered with suction. It seems probable that the leading-edge radius of curvature was too great.

A conventional section was therefore chosen for the present tests. A symmetrical 9 per cent thick aerofoil of the NACA 63 series was selected and a wedge-shaped tail was taken for ease of manufacture. The section, NACA 63A009, is shown in Fig. 1a and the ordinates are given in Table 1(a). The leading-edge radius of curvature is $0 \cdot 0063c$.

In order to investigate the effect of a more moderate increase in ϱ_L above the normal than was used on HSA V section, a modified section was obtained by truncating NACA 63A009 by 2 per cent of the chord at the leading edge and fairing in a thicker nose whose radius of curvature was $0 \cdot 010c$. The contour of the nose region of NACA 0009 ($\varrho_L = 0 \cdot 0089$) a section with good maximum lift and stalling characteristics, was used as a guide. The alterations to the wind-tunnel model are confined to the first 6 per cent of the chord, but owing to its shorter chord length, the ordinates of the modified section, referred to unit chord, are different from those of NACA 63A009. The new section has been designated NPL 321 ; its ordinates are listed in Table 1(b), and the nose shape is compared with the original in Fig. 1b.

2. *Experimental Arrangement.*—The tests were carried out in the National Physical Laboratory 13-ft × 9-ft Wind Tunnel on a model of 6-ft 6-in. span and 3-ft chord. The model was constructed from wood and was fitted with a detachable porous nose made in metal to give either NACA 63A009 or NPL 321 profile. The porous noses were designed to enable alterations in permeability and extent of porous suction to be readily made : their construction and the arrangement of the suction ducting within the model are shown in Fig. 1c and 1d. The basic surface was formed from brass sheet coarsely perforated with 30 $\frac{1}{8}$-in. diameter holes per square inch. Resistance to the suction flow was provided by up to five layers of J. B. Green's No. 406 Grade filter paper. Each layer of paper provided a resistance of 6 inches of water pressure difference per 1 ft/sec suction velocity through the surface. The surface was sealed where necessary with a thin sheet of impervious plastic sheeting to control the extent of the suction and the surface was finished with a tightly stretched skin of fine brass gauze of 140 threads per inch. The nose cavity was divided into three parts by solid ribs, and the sucked air in each part was removed by a separate duct. Each duct was connected outside the wing through a calibration pipe and a control valve to the suction pump. In order to measure a very wide range of suction quantities each calibration pipe consisted of a $\frac{3}{4}$-radius flow meter (for the large flows) into which an orifice disc could be inserted for measuring very small flows.

The lift coefficient was evaluated from the measured pressure distribution at mid-span. The pressure over the porous nose was measured by a number of small flanged tubes which were inserted through the filter paper and perforated surface and lay with their flanges embedded in the paper under the outer gauze skin. A check with a surface static-tube showed that owing to the negligible resistance of the gauze, these sub-surface static holes registered the correct static pressure.

The wing was fitted vertically in the 13-ft × 9-ft Wind Tunnel. The lower end was secured to a turntable set in the floor and the upper end was supported by a cantilever attached to the roof turntable. A large false ceiling 6-ft wide and 9-ft long was fitted at the upper end of the model to obtain two-dimensional flow conditions. Owing to the strong adverse gradients obtainable on the wing with boundary-layer suction, it was impossible to prevent a migration of the boundary layer of the tunnel floor and ceiling on to the ends of the model, and with critical suction quantities the breakdown of the flow over the model was by no means two-dimensional. Threads attached to the model showed, however, that the flow over the centre-section where the pressure distribution and the suction quantities were measured was reasonably uniform along the span.

3. *Scope of the Tests.*—The lift coefficient of the aerofoil, C_L, depends on five parameters. These are the incidence, α, the chordwise extent of suction round the surface s, the distribution of the suction within these limits, the total suction quantity per foot span Q, and the Reynolds number R $(= U_0c/\nu)$. The total suction quantity can be expressed non-dimensionally either in coefficient form C_Q $(= Q/U_0c)$ or in terms of the ratio of the mean velocity into the surface v_0 $(= Q/s)$ to the stream velocity, i.e., v_0/U_0.

The tests aimed at a general exploration of the effects of varying these parameters as it was obviously impossible to test all possible combinations. In consequence, none of the results should be regarded as necessarily being the most efficient or economical application of suction, although it may be apparent from the tests that, in particular cases, any additional improvement would be small.

As an initial simplification, the tests were, with one exception, carried out with a constant distribution of suction velocity round the surface (i.e., v_0/U_0 independent of s). The test in which the chordwise distribution of suction was altered (section 7) suggests that uniform suction does not provide the most economical arrangement, and the exploration of the controlling effect of the suction velocity on the growth of the boundary layer in an arbitrary pressure gradient is clearly a subject for fundamental investigation in more tractable conditions. On the model aerofoil, the provision of a specified suction distribution is difficult, but at speeds up to 120 ft/sec uniform suction velocity can be obtained simply by using up to four layers of filter paper with a large suction head to generate the suction flow. Above 120 ft/sec however, the suction head was comparable with the external static-pressure variation along the surface so it was necessary to remove strips of filter paper in the region of maximum external velocity in order to maintain uniform suction. This control, though tedious, enabled the variations in suction velocity to be kept within a ratio which was certainly less than 2 : 1. At a wind speed of 180 ft/sec the head available for suction was inadequate and the rise in C_L with increase of suction flow was limited by an incipient local outflow (section 5).

As a result of preliminary tests, an incidence of 14 deg, at which the aerofoil was well stalled without suction, was selected as a suitable incidence at which to carry out a detailed investigation of the effect of suction. At this incidence, the effect of varying the extent of suction is discussed in section 4, then, taking the optimum extent of suction, the effect of variation of Reynolds number on the quantity of suction is examined in section 5.

The variation of lift coefficient with incidence was investigated for the optimum extent of porous area (0 to 2·75 per cent of the chord round the upper surface) at a wind speed of 60 ft/sec. ($R = 1 \cdot 15 \times 10^6$) in section 6. The results obtained when a 20 per cent split flap at 60 deg deflection was added to the aerofoil are given in section 7.

The tests described in sections 6 and 7 were repeated on the modified aerofoil shape, section 8, and a comparison with the original section is made in section 9.

4. *Variation of the Extent of Distributed Suction.*—An optimum arrangement of suction was determined at a wind-speed of 60 ft/sec. ($R = 1 \cdot 15 \times 10^6$) and an incidence of 14 deg, since preliminary tests had shown that this incidence was a reasonable way beyond the zero-suction stall, which set in at 8 deg and gave $C_{L\,\max}$ at 11 deg incidence.

The wing was tested first with the full available extent of suction, which covered 15 per cent chord on both upper and lower surfaces. The extent on the lower surface was then progressively reduced by sealing with plastic sheeting ; the differences obtained in the relation between lift and suction are illustrated in Fig. 2. The lift coefficient with unseparated flow for the test without any suction on the lower surface (extent C, Fig. 2) is slightly less than that obtained with the other configurations. It was decided, however, to use 5 per cent extent of suction on the lower surface so as to ensure that at all incidences distributed suction was applied to the upper surface boundary layer from the stagnation point. Fig. 2 also shows a hysteresis in the effect of suction on the lift, from which it was decided to take all observations with increasing suction. This may give results that are occasionally pessimistic in suction quantity, but ensures that the lift can be obtained straightforwardly.

The extent of suction was next varied on the upper surface (Fig. 3). As the extent was reduced to 2·75 per cent chord, the suction quantity required to prevent separation steadily decreased despite a slight increase in suction velocity, but the lift coefficient with unseparated flow fell off. Below 2·75 per cent chord there was little further economy in C_Q. This suggested that subsequent tests should be carried out with 2·75 per cent chord extent of suction on the upper surface. This is a much smaller extent than on the lower surface, so an additional test was performed which suggested (Fig. 4) that the lower surface extent could be reduced to zero without ill effect.

A standard configuration of suction was therefore chosen for the subsequent tests, consisting of 2·75 per cent extent of suction on the upper surface from the leading edge, and no suction on the lower surface. With this extent, as with all others at 14 deg incidence, the stall due to the reduction of suction at constant incidence occurred through the sudden expansion of a bubble of separation near the leading edge so that it covered the whole aerofoil. Extra tests have shown that at higher incidences the breakdown of flow could also occur as a forward movement of a turbulent separation from the rear of the aerofoil. In this case, an increase in the *extent* of the upper-surface suction prevented the occurrence of the turbulent separation, but the total suction quantity required to obtain unseparated flow was greater than with the lesser extent of suction.

5. *Scale Effect on Suction Quantity.*—The tests of the section at 14-deg incidence with 2·75 per cent extent of suction on the upper surface and no suction on the lower surface, covered a wide range of wind speeds. At and above a wind speed of 120 ft/sec the number of layers of filter paper was reduced locally in the region of minimum pressure in an attempt to maintain a reasonably uniform distribution of suction velocity. The adjustment failed at 180 ft/sec where for the same peak value of the non-dimensional pressure coefficient (C_p) that was obtained at lower speeds, the peak pressure would have exceeded the suction pressure obtained by the pump. In fact, a localized outflow at the nose created a small bubble of separation and in consequence the peak suction was reduced. The true conditions of unseparated flow were therefore not reached at 180 ft/sec. The relations which were obtained between C_L and C_Q at the various speeds of test are shown in Fig. 5.

There is considerable scale effect on the values of the lift coefficient with unseparated flow, higher values of C_L being obtained at the larger Reynolds numbers. The value of C_Q required to obtain a given C_L does not therefore give a suitable indication of the scale effect on suction quantity. Instead, the suction-quantity coefficient required just to prevent separation of the flow has been considered, and is plotted against Reynolds number in Fig. 6. As separation is not overcome along the whole span of the aerofoil at once, the increase of lift with suction is not discontinuous, but spread over a small range of C_Q. This whole range of C_Q in which C_L rises rapidly has been taken as the critical condition in plotting Fig. 6. The resulting points suggest a curve in which C_Q is proportional to $1/R^{1/2}$ for the lower values of the Reynolds number, but decreases rather more slowly at the higher Reynolds numbers. The theoretical result that $C_Q\sqrt{R}$ should remain constant refers to boundary layers which are wholly laminar. In the experiments the boundary layer appears to have become turbulent at the higher Reynolds numbers.

6. *Variation of Lift with Incidence and Suction Quantity.*—The lift coefficient of the wing with suction applied over the first 2·75 per cent of the chord was measured at a wind speed of 60 ft/sec. ($R = 1\cdot 15 \times 10^6$) up to an incidence of 21-deg. The increase in C_L obtained at a fixed incidence as the suction was applied and separation overcome is shown in Fig. 7. Considerable scatter was noticed between observations that were repeated later during the tests,

At 16-deg incidence, for example, measurements were also taken with the original gauze skin replaced by a gauze which had been rolled to reduce its surface roughness. There was no significant difference either in the stall and the value of $C_{L\,\max}$ without suction, or in the behaviour with suction. Nevertheless, appreciable differences in actual values of C_L and $(v_0/U_0)\sqrt{R}$ were found (Fig. 7). The velocity distribution round the aerofoil for three of the C_L's measured at 16-deg is shown in Figs. 8a, 8b and 8c : with separation prevented, the distribution approximates closely to the theoretical.

The relations between C_L and incidence for various values of the suction quantity (Fig. 9) were obtained by cross-plotting from experimental relations between C_L and $(v_0/U_0)\sqrt{R}$ at constant incidence such as Fig. 7. Without suction, the stall obtained by increasing incidence is due to the rearward expansion of a bubble of separation, and there appear to be two régimes of flow giving slightly different values of C_L, a result which was also obtained on HSA V. With moderate amounts of suction, the stall is delayed to higher incidences where the adverse gradient behind the porous region is more severe. Hence the expansion of the bubble of separation when it does occur is more violent and the loss in lift more sudden than without suction. The stall becomes gentle again at the highest suction quantities and incidences as a turbulent separation sets in from the trailing edge in addition to the bubble of separation at the nose. This turbulent separation could not be suppressed except by excessive suction quantities applied over an extended area (*see* section 7).

7. *Effect of Split Flap, and of Extra Suction.*—A 20 per cent chord split flap was made from aluminium sheet and attached to the aerofoil at a deflection of 60 deg. The variation of lift coefficient with incidence and suction quantity is shown in Fig. 10. Without suction the effect of the flap is to raise the maximum C_L by 0·90 from 0·83 or 0·89 to 1·74. With the value of C_Q of 0·0034, the increment is only 0·55, $C_{L\,\max}$ increasing from 1·50 to 2·05.

It was realized that the $C_{L\,\max}$ attainable was limited by the amount of suction available. In demonstration of this, Fig. 11 illustrates the lift incidence relations both with and without a flap that were obtained with a C_Q of 0·013. For this experiment, the extent of suction was increased to 15 per cent so as to prevent turbulent separation at the rear, and the distribution of resistance was made non-uniform so that the estimated suction velocity through the first 1 per cent of the chord was about double the velocity elsewhere. The C_Q value is excessive for any practical application, but the experiment indicates the scope for fundamental investigations to determine the suction quantities necessary to prevent separation under any given adverse pressure gradient. Fig. 11 also shows that even with the high suction quantities, the increments of C_L due to suction are still lower with the flapped aerofoil than with the plain aerofoil.

8. *Tests of Modified Section, NPL* 321.—The geometrical derivation of the modified section NPL 321 has already been described in the Introduction and in Table 1. The effect of the increase in nose radius from 0·0063*c* to 0·0100*c* in alleviating the severity of the adverse velocity gradients near the nose at high angles of incidence is illustrated by the theoretical velocity distributions given in Fig. 12.

The variation of lift with incidence was measured with suction applied over the first 2·75 per cent of the chord of the upper surface as on the original aerofoil. The results are shown in Fig. 13 for the plain section, and in Fig. 14 for the section with 20 per cent split flap at 60-deg deflection.

The increase in lift that is obtained on the plain section as suction is applied is probably due to a reduction in the thickness of the region of separated flow. When the C_Q is above about 0·0014 (Fig. 13) there is generally no separation at the nose and the further increases in C_L that are obtained at incidences above about 13 deg as suction is increased occur through the gradual suppression of a turbulent separation from the rear of the section. However, above 16 deg not even the highest suction available could prevent a turbulent separation occurring on the outer sections of the model, though the flow over the centre-section was satisfactory.

This phenomenon is responsible for the kink in the lift curve, and the stall on the centre-section for the highest C_Q's was abrupt as a complete breakdown of the flow over the centre-section occurred. With the split flap in position, the stall was sudden both with and without suction.

For NPL 321 with split flap, the effect of variation of extent of suction on the quantity required to prevent separation of the flow was investigated at 10-deg and 15-deg incidence (Figs. 15 and 16). At both incidences, the breakdown of the flow on decreasing suction quantity was abrupt, but for the larger extents of suction (4 and 5 per cent), a ragged turbulent separation was observed on the outer sections of the aerofoil. There was an increasing economy in the suction quantity required to prevent separation as the extent of suction was reduced to 2 per cent ; but, as on the original section, the lift coefficient with unseparated flow fell off slightly.

The reduction in extent of suction was carried to the limit by reducing the width of the porous area to a bare $\frac{1}{10}$ in. $(0 \cdot 28$ per cent chord) at the leading edge. This was completely ineffective but was made to work by moving it to 1 per cent of the chord, although the quantity then required to prevent separation was very large. But considered as a slot suction aerofoil for high lift, the slot width would be very considerably reduced below $\frac{1}{10}$ in. with a resulting economy in suction quantity.

9. *Comparison between the Aerofoil Sections and Discussion of Results.*—The maximum values of the lift coefficients measured without suction on the two aerofoils are compared in Table 2 with the values expected from a consideration of N.A.C.A. test results on symmetrical aerofoils[3]. The values of $C_{L\max}$ for the plain aerofoils are rather less than are predicted ; this may possibly be due to the roughness of the gauze covering at the nose which could also similarly affect the results obtained with small chordwise extents of suction. The 20 per cent split flaps, however, are fully effective in increasing $C_{L\max}$ by $0 \cdot 9$.

The comparison of the measured values of $C_{L\max}$ with and without suction is given in Table 3. The differences between adjacent entries in the table are given in brackets. A moderate amount of suction, $C_Q = 0 \cdot 0034$, applied to the plain aerofoils produces an increase in $C_{L\max}$ of about $0 \cdot 65$. The effect of the addition of suction to the flapped aerofoils is disappointing. In the case of NACA 63A009, the lift increment is only one half, and for NPL 321, two-thirds the corresponding lift increments obtained on the plain aerofoils.

The effect of section shape on performance may be summarized by saying that change from the NACA 63A009 aerofoil to the NPL 321 shape resulted in an increase in $C_{L\max}$ of $0 \cdot 1$ in all conditions except that where suction was applied and the flap was deflected. In this case the increase was $0 \cdot 3$. The smallness of these gains due to section shape compared with those due to the application of suction to either section suggests that it is hardly worthwhile seeking improved performance by further refinements to the aerofoil shape, especially as any further thickening of the nose will mar the low incidence performance of the section by spoiling the low-drag characteristics and raising the critical Mach number of the section*.

The suction quantities quoted as necessary to obtain given increments of C_L are probably on the pessimistic side owing to the crude control of the chordwise variations in suction velocity. Nevertheless, if extrapolation of the experimental quantities $(C_Q \sim 0 \cdot 0035)$ to flight Reynolds numbers can be obtained with $C_Q\sqrt{R}$ a constant, the quantities required for full-scale tests will be very reasonable. Tests were not carried out with higher suction quantities as it was found that the filter paper was clogging up with dust too rapidly, and also in view of the following important consideration.

Nose suction operates to increase $C_{L\max}$ by extending the lift curve to higher incidences, and therefore depends on the attainment of higher suction peaks over the upper surface of the

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* It is not possible to include the earlier experiments on the HSA V section in the comparison as these tests were less extensive and the values of $C_{L\max}$ with suction applied were not measured. Within the limitations of the HSA V tests, the C_L's obtained were very closely equal to those obtained on the NACA 63A009 section for the same suction quantities, but the present tests extend to much higher C_Q's.

aerofoil. In the present tests, for example, peak pressure coefficients in excess of −25 were obtained, corresponding to surface velocities greater than five times that of the free-stream. Clearly, such velocities would not be obtained in flight conditions owing to compressibility effects. Hence any further tests must be carried out at full-scale landing speeds. This was not possible with the present apparatus owing to a lack of suction head.

10. *Conclusions.*—The application of distributed suction at the nose has raised the maximum lift coefficient of the 9 per cent thick plain aerofoil by 0·65 with an accompanying increase of incidence of about 10 deg for a suction-quantity coefficient of 0·0034 at 60 ft/sec. With a 20 per cent split flap deflected 60 deg, the maximum lift increment was 0·88 without suction. When suction was applied a further gain of 0·31 was obtained. Larger lift coefficients could be obtained with extra suction at higher angles of incidence. The improvements obtainable in maximum lift coefficient for a given suction quantity by refinements to the aerofoil shape were small, though the type of stall could be affected.

In the application of distributed suction to reduce the landing speed of a heavily loaded aircraft, it is important that preparatory wind-tunnel tests should be made at the full-scale speed (as well as at Reynolds numbers close to those of flight), since at high angles of incidence the velocity peak at the nose, measured in the present tests, was so high as to be seriously modified by compressibility effects.

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TABLE 1

Details of Aerofoil Sections

(*a*)

NACA 63A009

$t/c = 0 \cdot 0900$
$\varrho_L/c = 0 \cdot 00631$

x/c	y/c
0	0
0·005	0·00749
0·0075	0·00906
0·0125	0·01151
0·025	0·01582
0·05	0·02196
0·075	0·02655
0·10	0·03024
0·15	0·03591
0·20	0·03997
0·25	0·04275
0·30	0·04442
0·35	0·04498
0·40	0·04471
0·45	0·04353
0·50	0·04152
0·55	0·03880
0·60	0·03549
0·65	0·03165
0·70	0·02740
0·75	0·02290
0·80	0·01836
0·85	0·01382
0·90	0·00927
0·95	0·00472
1·00	0·00019

Wedge semi-angle
at tail = 5·77 deg

(*b*)

NPL 321

$t/c = 0 \cdot 0918$
$\varrho_L/c = 0 \cdot 0100$

x/c	y/c
0	0
0·005	0·00972
0·0075	0·01173
0·0125	0·01476
0·025	0·01985
0·05	0·02599
0·075	0·02997
0·10	0·03309
0·15	0·03824
0·20	0·04182
0·25	0·04425
0·30	0·04558
0·35	0·04590
0·40	0·04541
0·45	0·04403
0·50	0·04185
0·55	0·03904
0·60	0·03560
0·65	0·03170
0·70	0·02740
0·75	0·02290
0·80	0·01836
0·85	0·01382
0·90	0·00927
0·95	0·00472
1·00	0·00019

Wedge semi-angle
at tail = 5·77 deg

Notes :—

(*a*) Actually the ordinates forward of the position of maximum thickness are those of NACA 63–009. They are everywhere within 0·00036 of those for NACA 63A009 but give a slightly larger leading-edge radius.

(*b*) NPL 321 was derived by diminishing the chord of NACA 63A009 by 0·02 at the nose and fairing into this section over the first 6 per cent of the chord a shape based on the nose of NACA 0009 modified so that the leading-edge radius of the new section (ϱ/c) was 0·010 [ϱ/c for NACA 0009 is 0·0089].

TABLE 2

Comparison of the Measured and Predicted Values of the Maximum Lift. Lift Cofficients of NACA 63A009 *and* NPL 321 *Sections* (*Without Suction*)

	NACA 63A009	
	Plain aerofoil	With 20 per cent split flap at 60 deg
Measured value of $C_{L\,\max}$	0·83 to 0·89	1·74
Predicted value* of $C_{L\,\max}$	1·1	1·8

	NPL 321	
	Plain aerofoil	With 20 per cent split flap at 60 deg
Measured value of $C_{L\,\max}$	0·96	1·90
Predicted value* of $C_{L\,\max}$	1·3	2·1

* Predicted values were taken from Ref. 3.

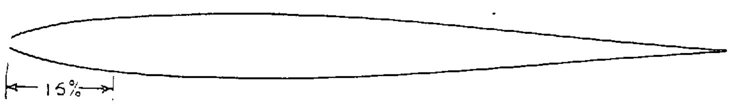
TABLE 3

Comparison of the Measured Maximum Lift Coefficients with and without Suction on NACA 63A009 *and* NPL 321 *Sections*

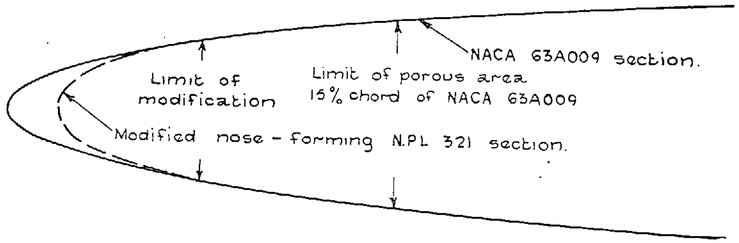
	$C_{L\,\max}$ on NACA 63A009		
C_Q	0		0·0034
Plain aerofoil	0·83 to 0·89	(0·64)	1·50
	(0·88)		(0·55)
With 20 per cent split flap at 60 deg	1·74	(0·31)	2·05

	$C_{L\,\max}$ on NPL 321		
C_Q	0		0·0034
Plain aerofoil	0·96	(0·67)	1·63
	(0·94)		(0·70)
With 20 per cent split flap at 60 deg	1·90	(0·43)	2·33

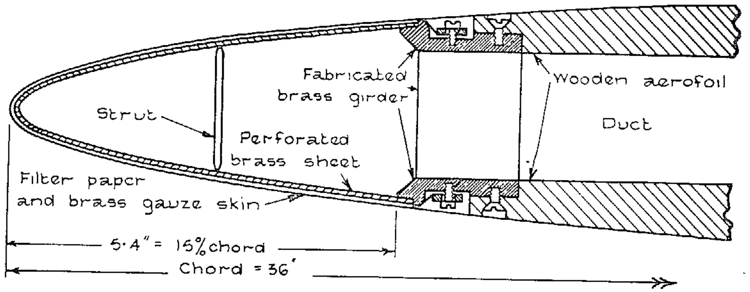
	Increase in $C_{L\,\max}$ due to change of section from NACA 63A009 to NPL 321	
C_Q	0	0·0034
Plain aerofoil	0·1	0·13
With 20 per cent split flap at 60 deg	0·16	0·28



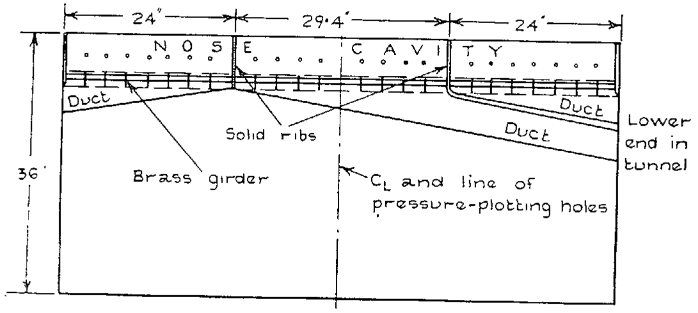
(a) NACA 63A009 aerofoil section.



(*b*) Comparison of NPL 321 and NACA 63A009 sections.



(c) Detail of porous nose



(d) Plan of wing showing arrangement of suction ducts.

FIG. 1.

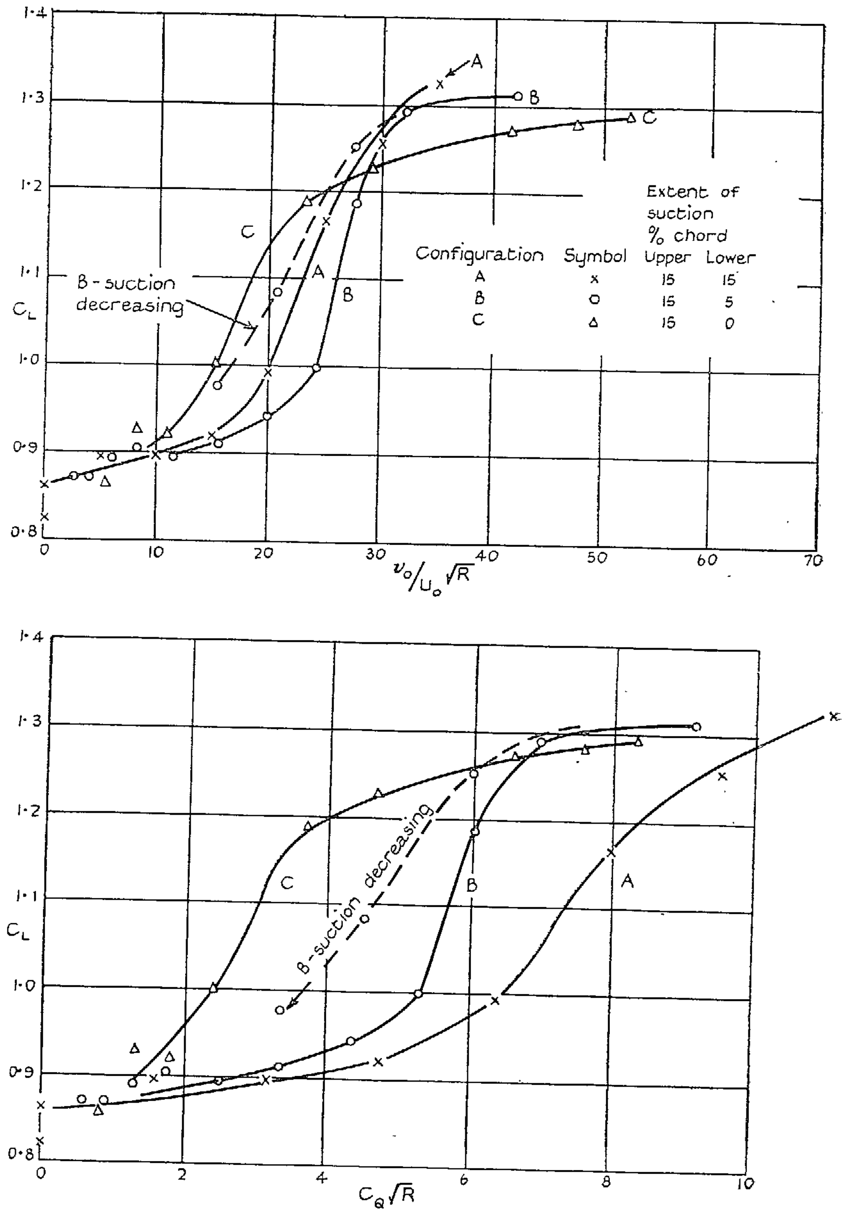


FIG. 2. The effect on lift of the variation of the extent of suction on the lower surface. NACA 63A009. $\alpha = 14$ deg. $U_0 = 60$ ft/sec. $R = 1{\cdot}15 \times 10^6$.

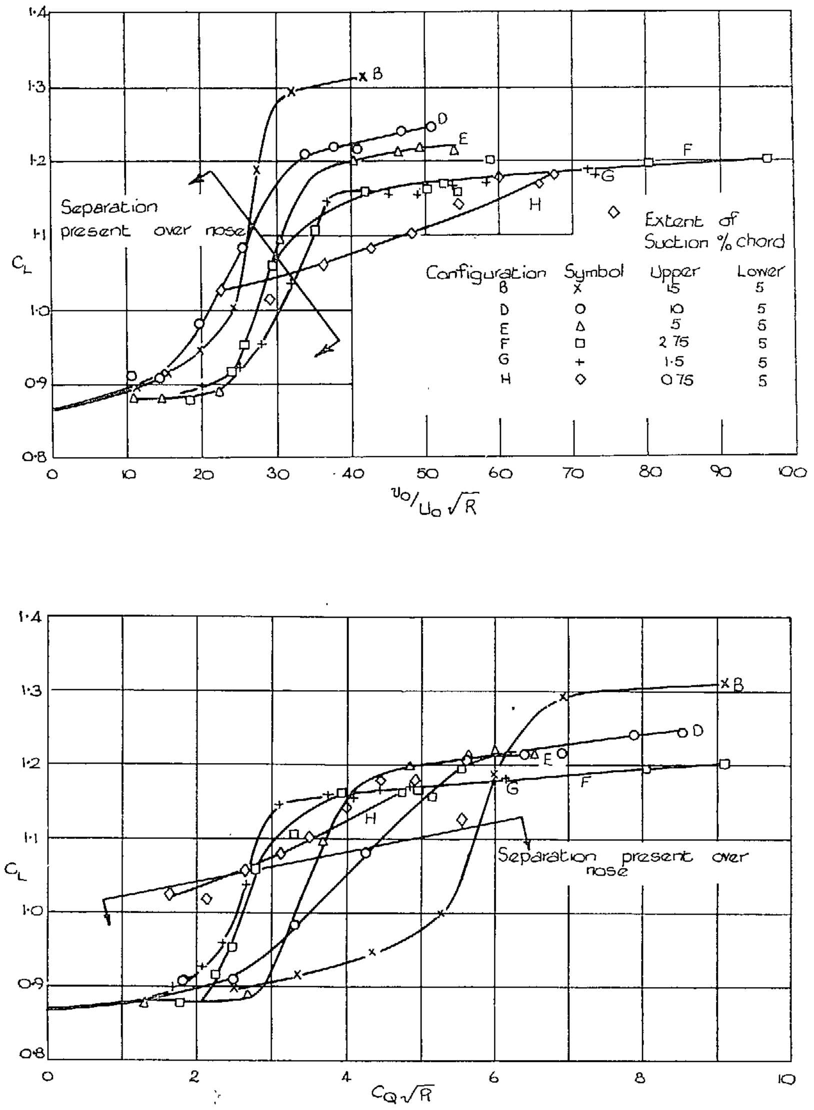


FIG. 3. The effect on lift of variation of the extent of suction on the upper surface. NACA 63A009. $\alpha = 14$ deg. $U_0 = 60$ ft/sec. $R = 1\cdot15 \times 10^6$.

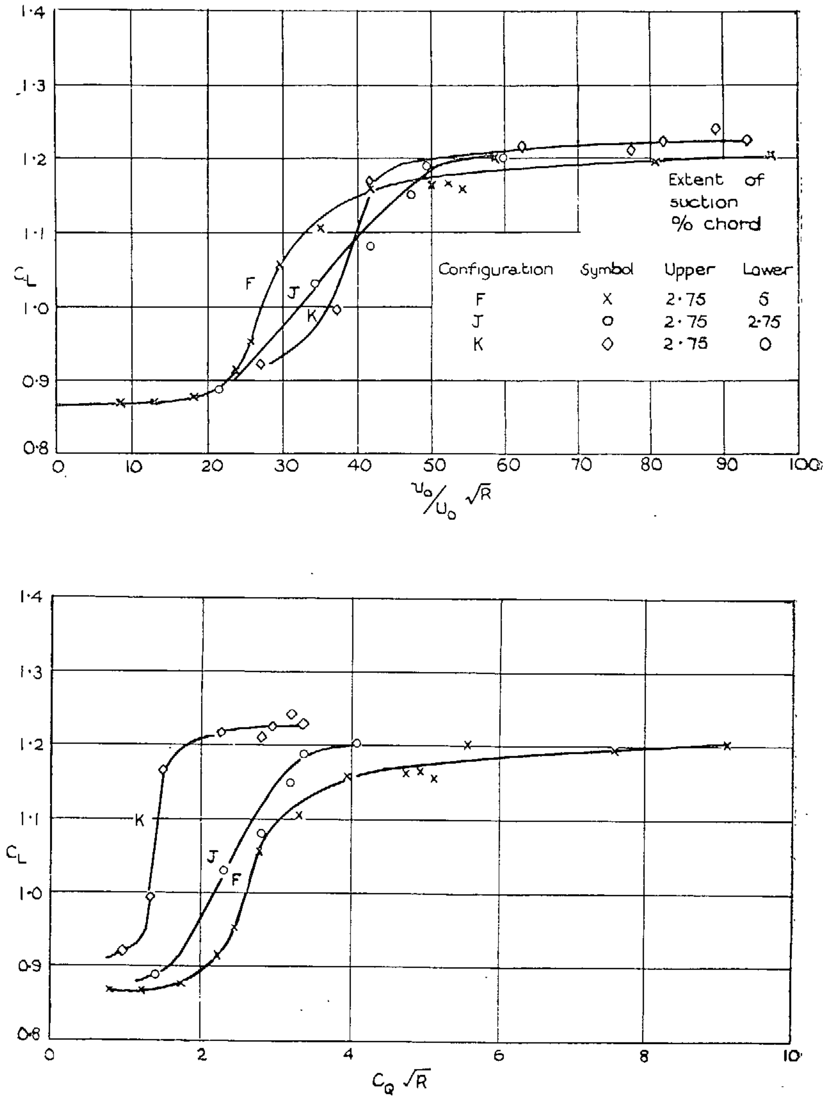


FIG. 4. The effect on lift of the variation of the extent of suction on the lower surface. NACA 63A009. $\alpha = 14$ deg. $U_0 = 60$ ft/sec. $R = 1\cdot15 \times 10^6$.

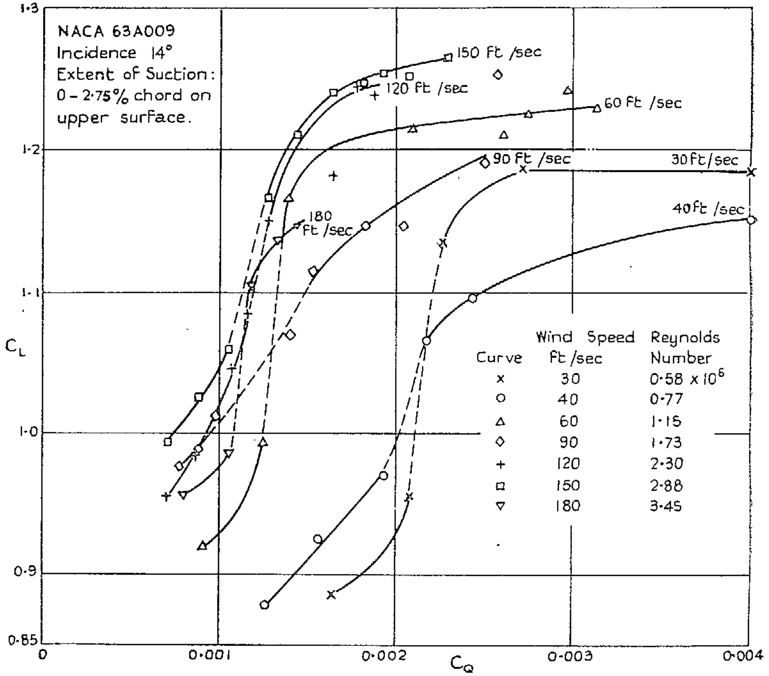


FIG. 5. Variation between lift and suction quantity at various wind speeds. NACA 63A009.

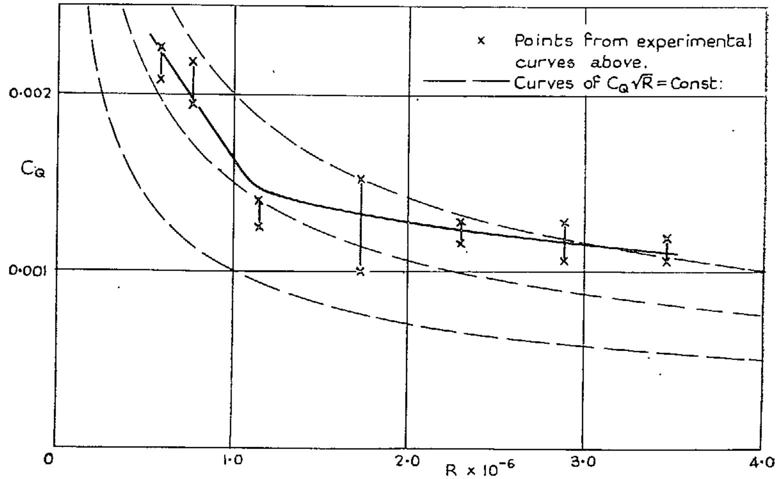


FIG. 6. Variation with Reynolds number of C_Q to prevent separation. NACA 63A009.

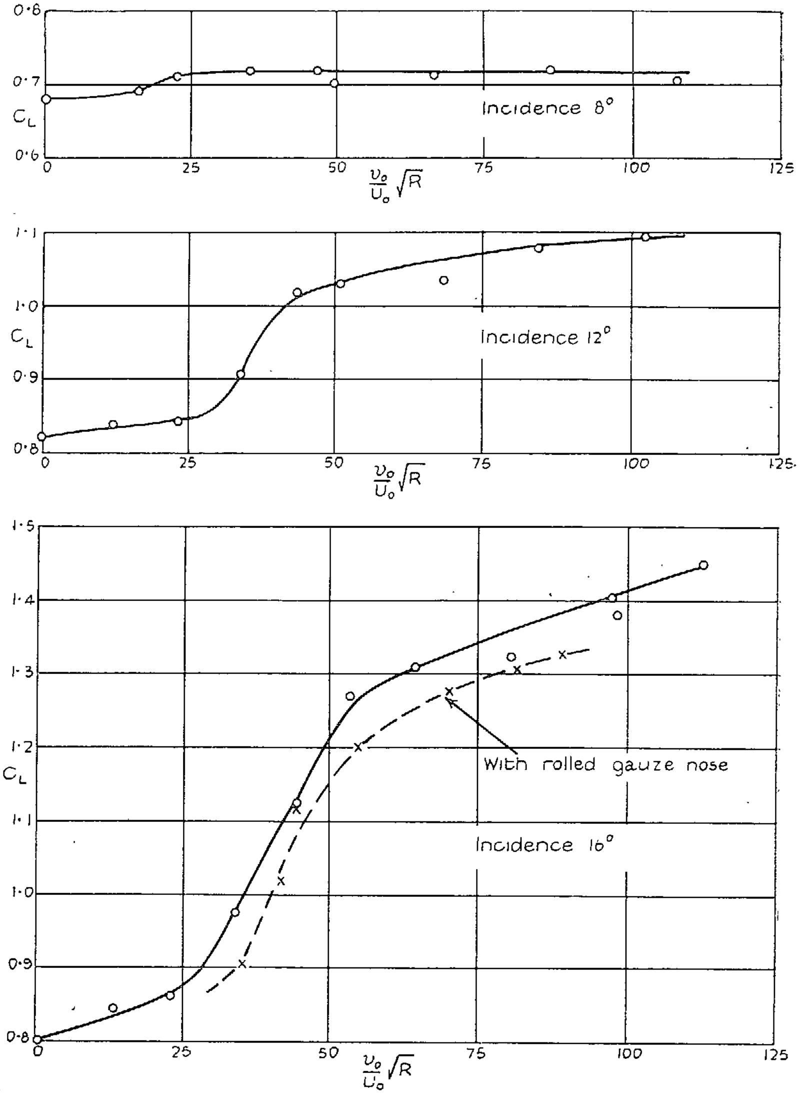


FIG. 7. Variation of lift coefficient with suction quantity at various incidences. NACA 63A009. Extent of suction 0 to 2·75 per cent chord on upper surface only. $U_0 = 60$ ft/sec. $R = 1{\cdot}15 \times 10^6$.

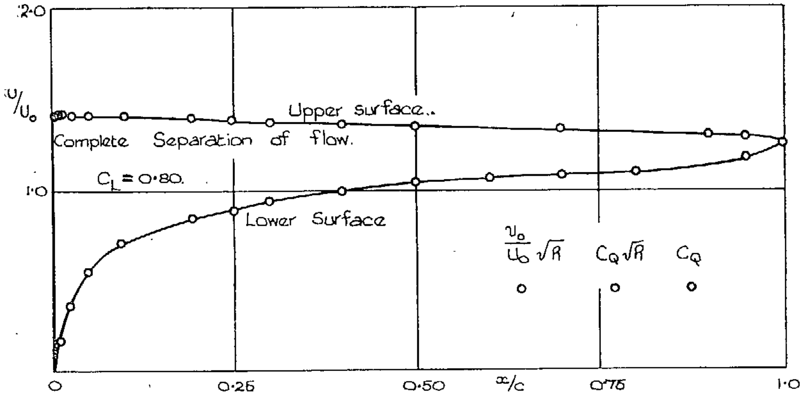


FIG. 8a.

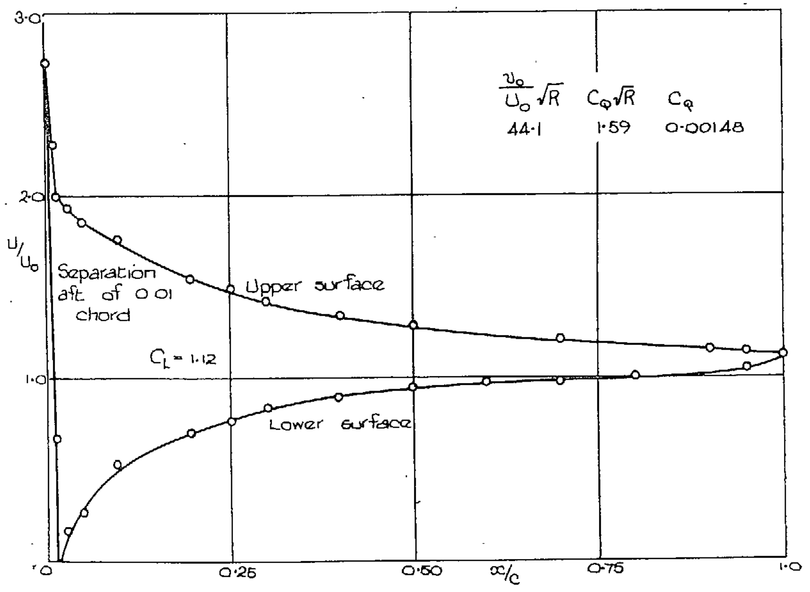


FIG. 8b.

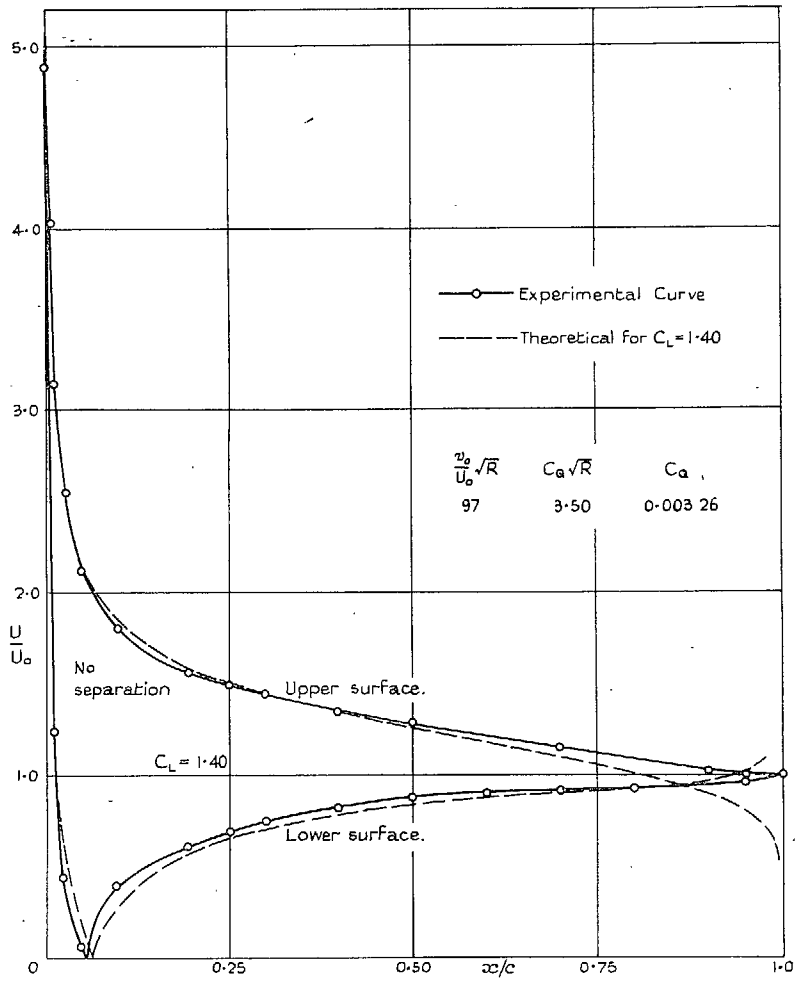
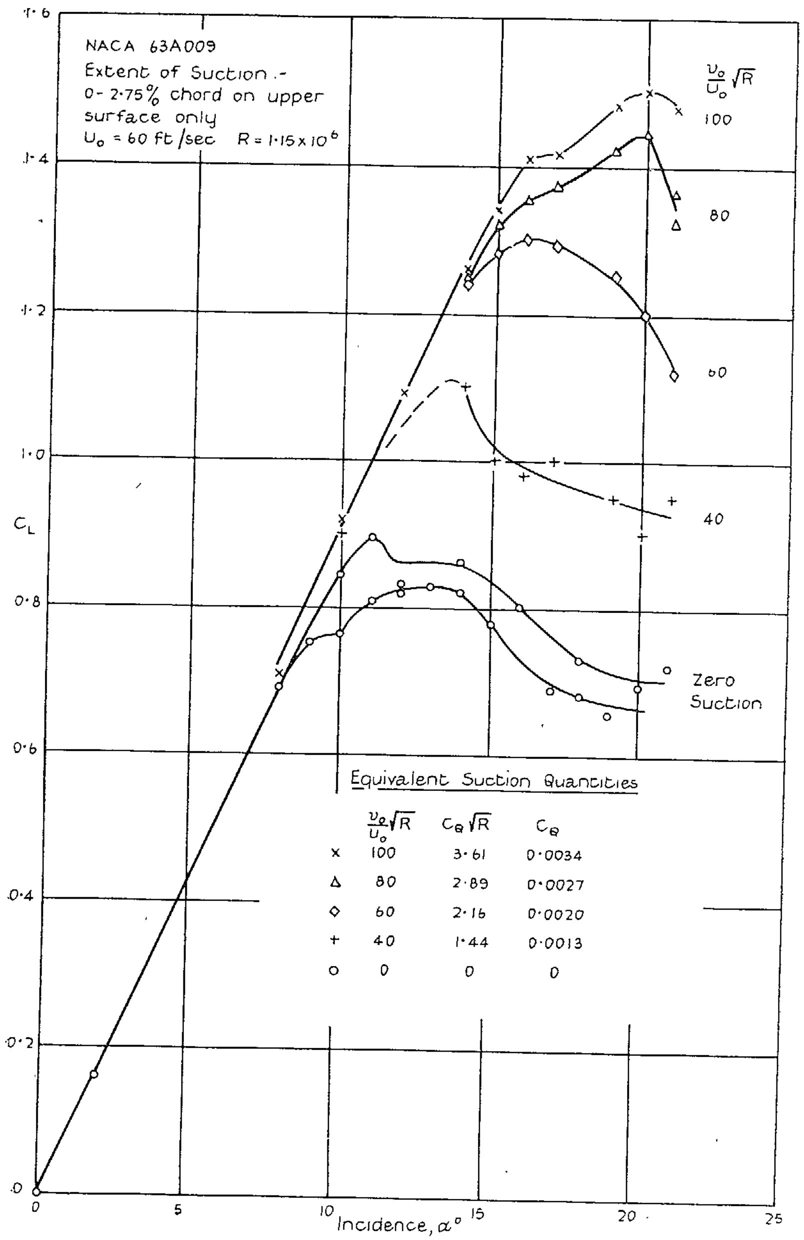


FIG. 8c.

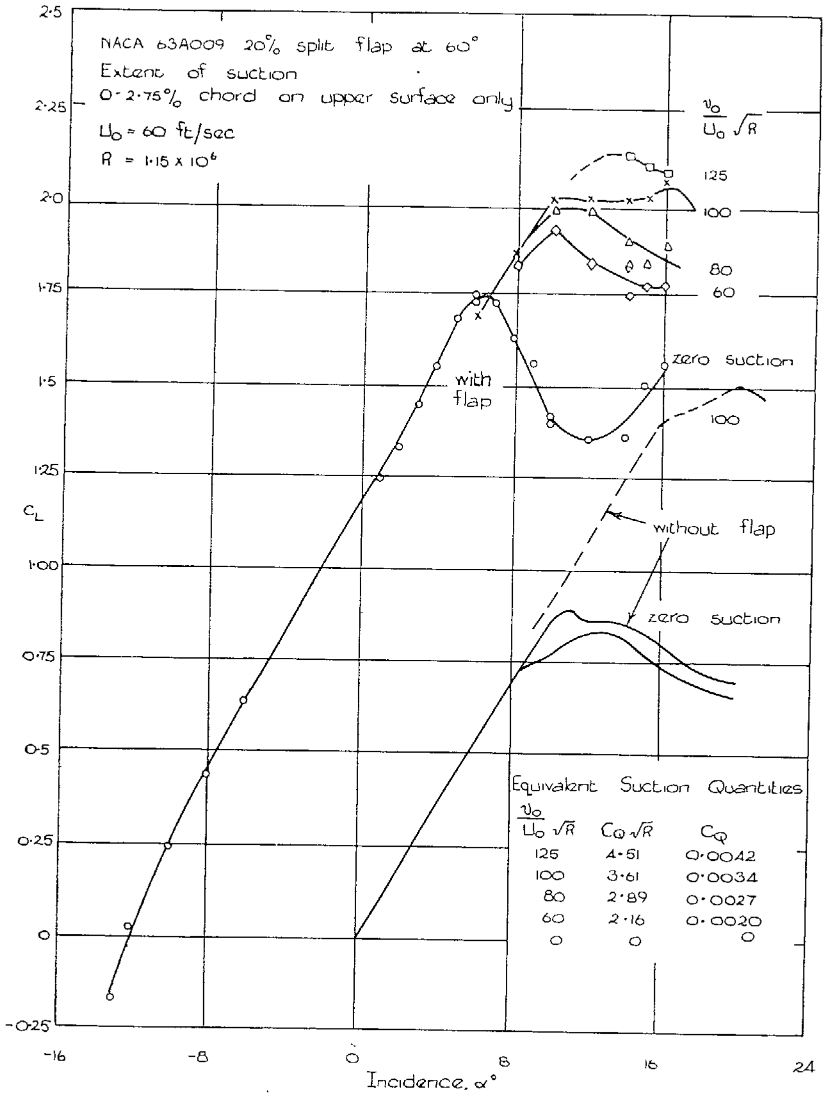
FIGS. 8a, 8b and 8c. Variation of velocity distribution on NACA 63A009 with suction quantity. $\alpha = 16$ deg. $U_0 = 60$ ft/sec. $R = 1\cdot5 \times 10^6$. Suction 0 to 2·75 per cent chord on upper surface.



Equivalent Suction Quantities

	$\frac{v_0}{U_0}\sqrt{R}$	$C_Q\sqrt{R}$	C_Q
×	100	3·61	0·0034
△	80	2·89	0·0027
◇	60	2·16	0·0020
+	40	1·44	0·0013
○	0	0	0

FIG. 9. Variation of lift coefficient with incidence and suction quantity. NACA 63A009.



Equivalent Suction Quantities

$\frac{v_0}{U_0}\sqrt{R}$	$C_Q\sqrt{R}$	C_Q
125	4·51	0·0042
100	3·61	0·0034
80	2·89	0·0027
60	2·16	0·0020
0	0	0

FIG. 10. Variation of lift coefficient with incidence and suction quantity. NACA 63A009 with split flap.

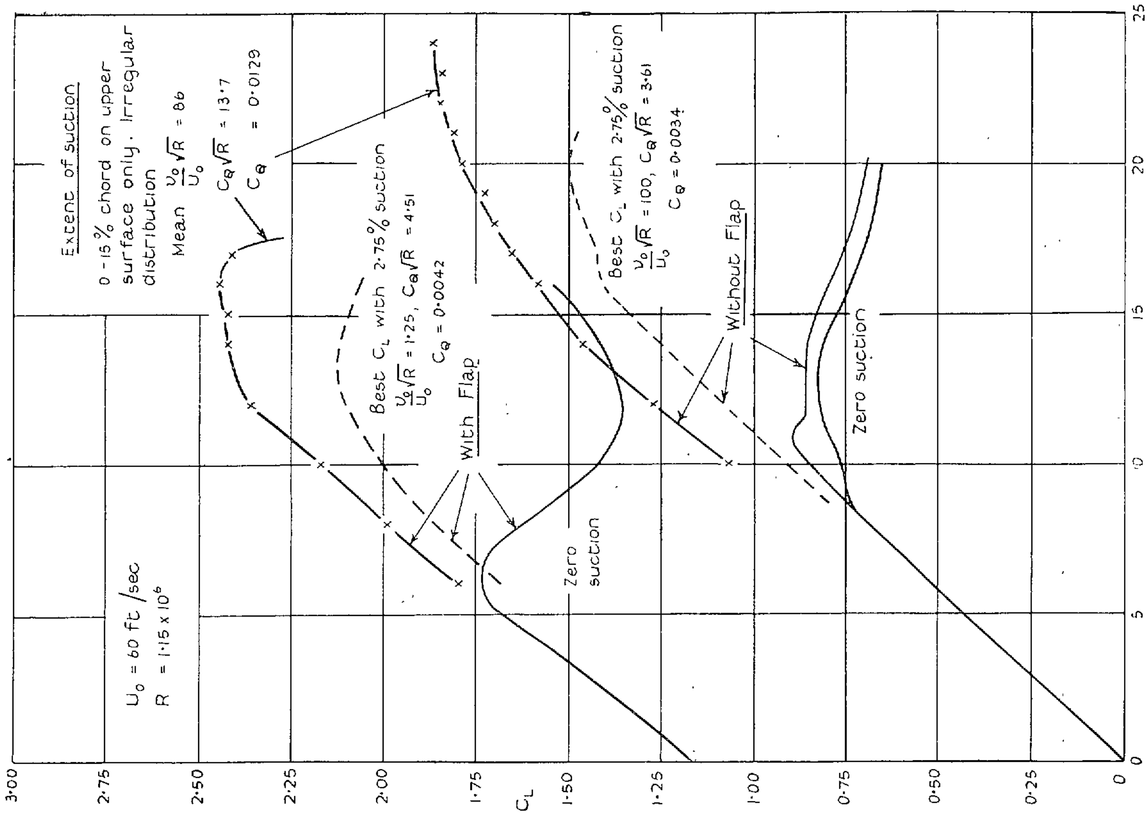


FIG. 11. Effect on lift coefficient of large suction quantities. NACA 63A009.

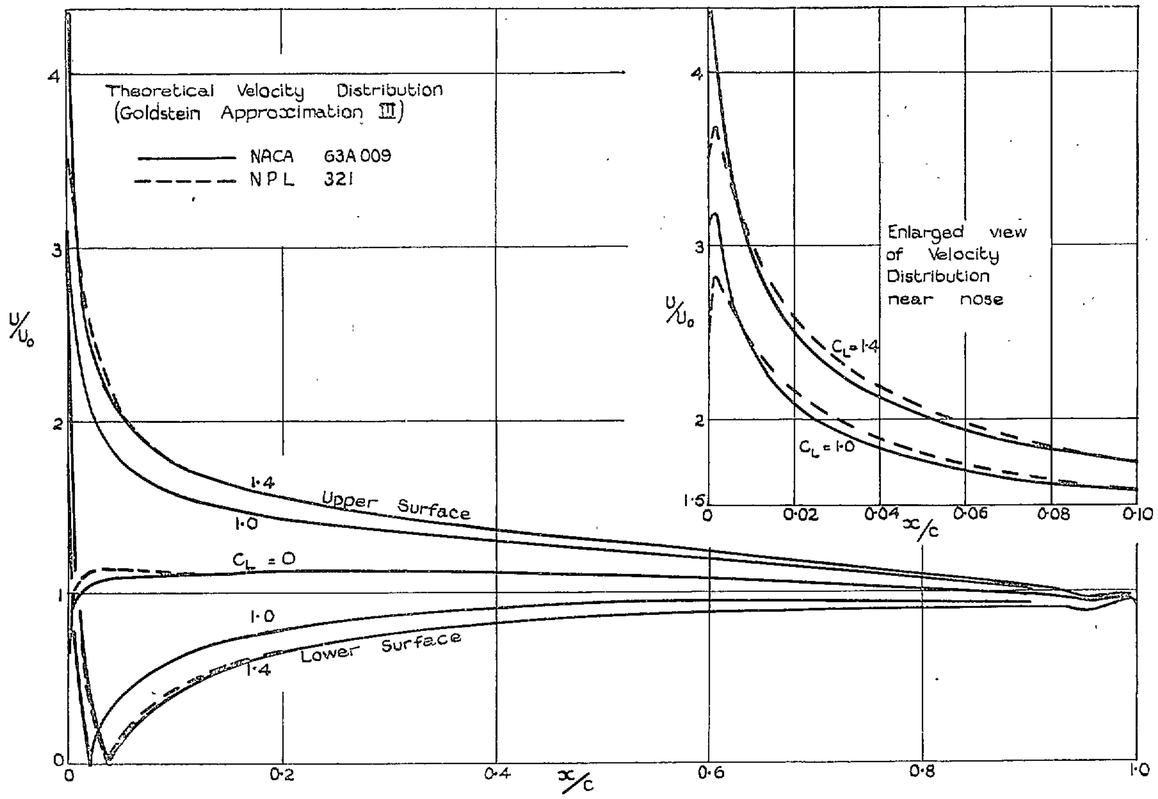


FIG. 12. Theoretical velocity distribution on NACA 63A009 and NPL 321 aerofoil sections.

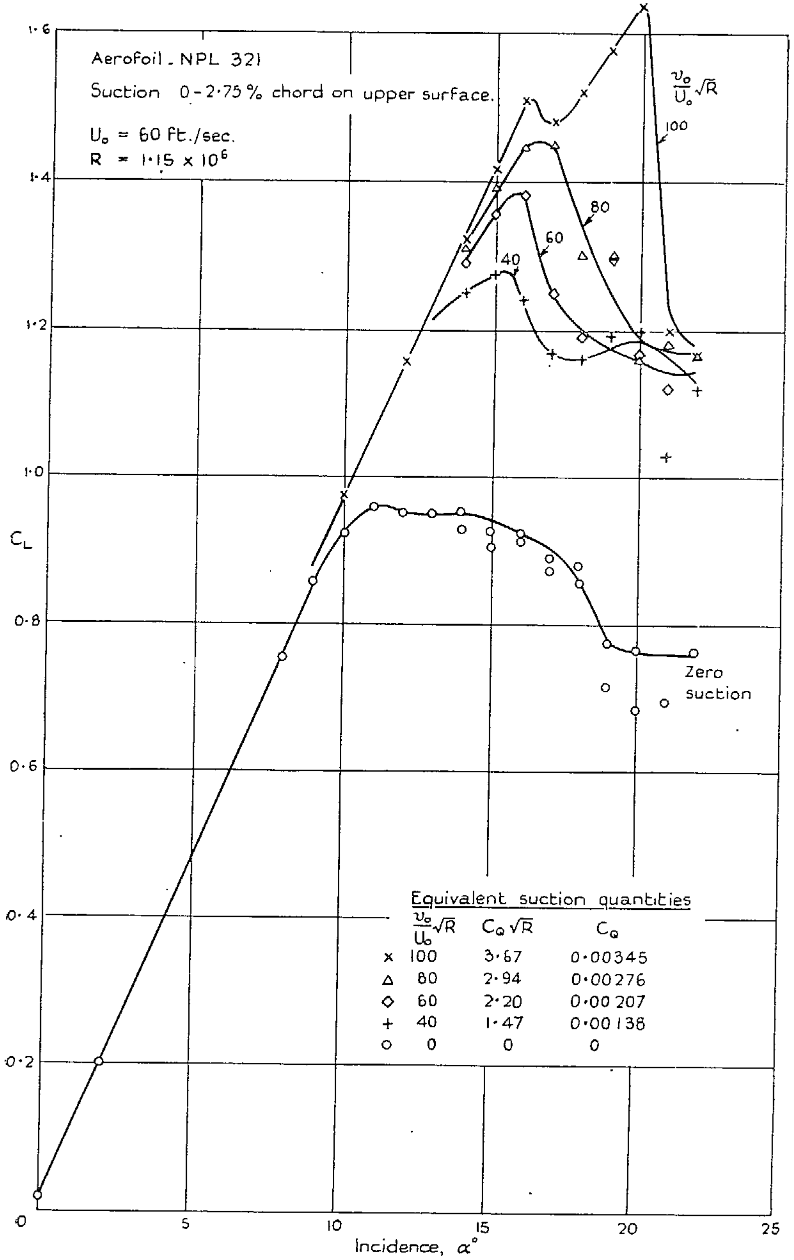


FIG. 13. Variation of lift coefficient with incidence and suction quantity. NPL 321 section.

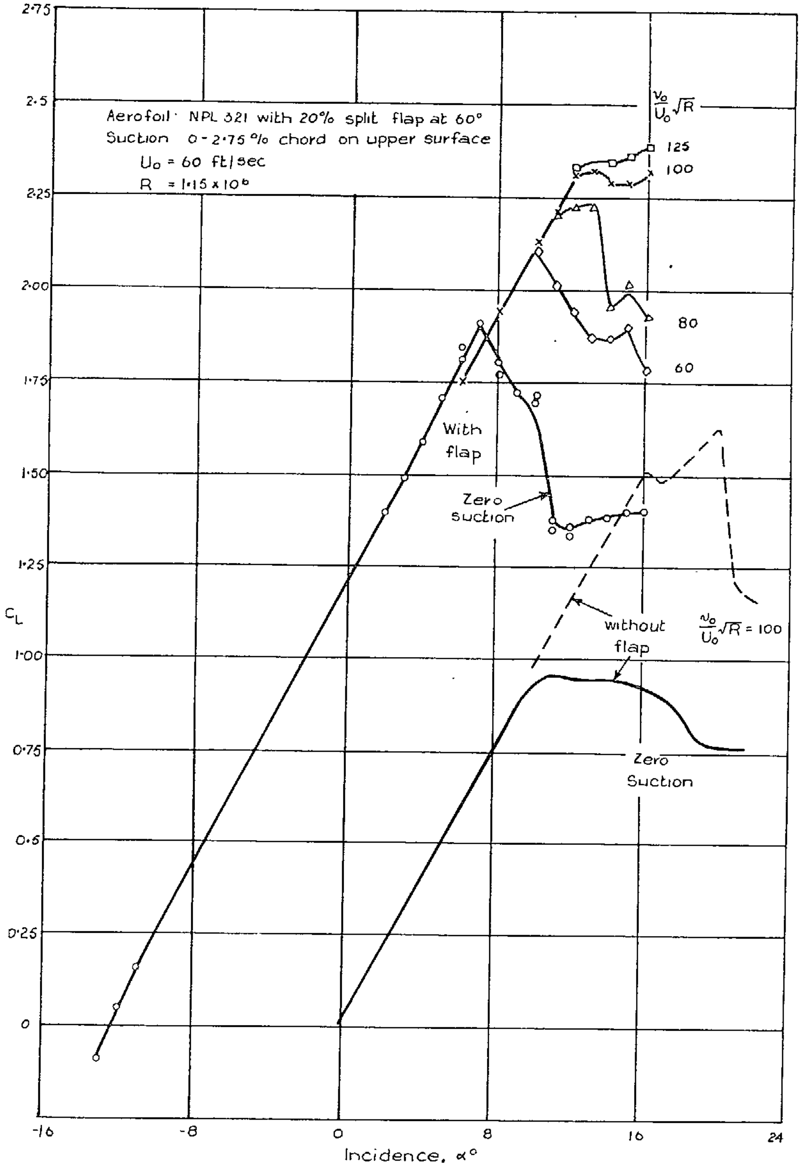


FIG. 14. Variation of lift coefficient with incidence and suction quantity. NPL 321 section with split flap.

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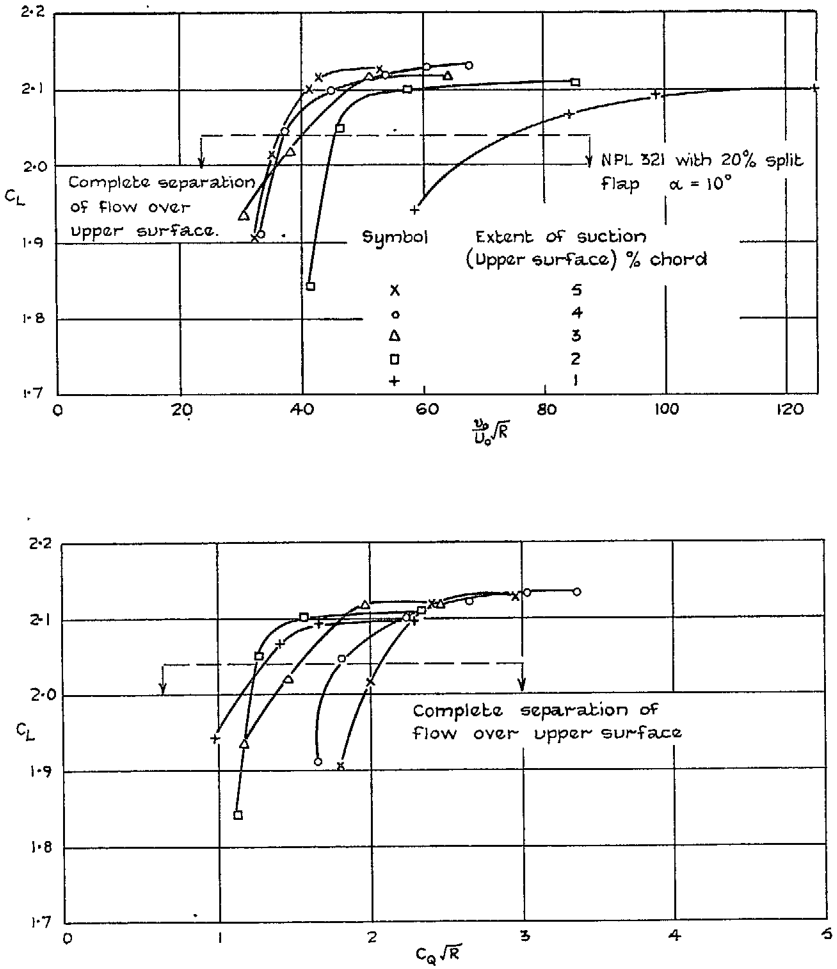

FIG. 15. The effect on lift of variation of the extent of suction. NPL 321 with split flap. $\alpha = 10$ deg. $U_0 = 60$ ft/sec. $R = 1 \cdot 15 \times 10^6$.

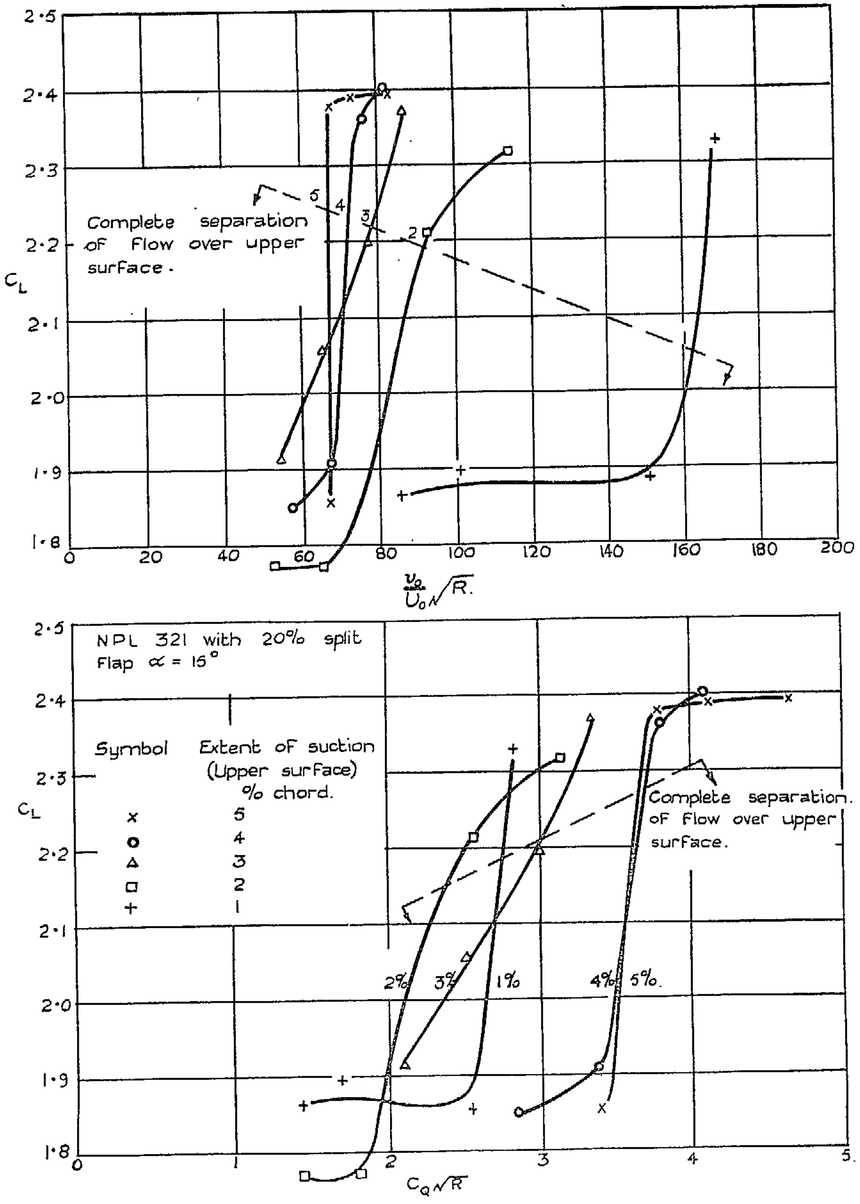

FIG. 16. The effect on lift of variation of the extent of suction. NPL 321 with split flap. $\alpha = 15$ deg. $U_0 = 60$ ft/sec. $R = 1 \cdot 15 \times 10^6$.

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